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# SHELTER HABITABILITY STUDIES — ODORS AND REQUIREMENTS FOR VENTILATION

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## INTRODUCTION

Personnel shelters are essential for survival from the immediate devastating effects of nuclear weapons. When a large number of individuals are occupying a protective shelter for approximately two weeks, or until the radioactivity of fallout drops to a safe level, numerous habitability problems arise. One of these problems concerns the effect and control of odors within shelters. When the outdoor air supply becomes deficient due to failure of the air conditioning system, or when the ventilation system must be shut down, the atmosphere can become objectionable from body and smoke odors.

Project Y-F011-05-401(b), Shelter Habitability Studies, was undertaken to study, among other factors, the effects of body odor and tobacco smoke on shelter occupants, and to establish minimum ventilation requirements for the removal of these odors in order to maintain a comfortable atmosphere.

## GENERAL DISCUSSION OF ODOR

In odor control work, the human nose is a very sensitive device which can detect minute quantities and qualities of odors in the air. However, the chemical and mechanical devices used in odor control work can measure more accurately the quantity of odor in terms of parts per million of odor in the air than can the nose. Many of these devices dilute odorous vapors to various concentrations by means of measured streams of air, ultimately depending upon the appraisal by the human nose.

### Body Odors

Body odors within a crowded, inadequately ventilated room, are unpleasant when one first enters; however, after having become adapted to the room conditions, people are no longer acutely conscious of foul odors because of fatigued olfactory organs. Under comfortable conditions of temperature and humidity, poor air quality is variously described as stuffiness, closeness, heaviness, and staleness. The occupants of an enclosed room can discern good air from bad, but cannot discriminate intermediate degrees.[1] Noxious odors in air may affect the health of occupants by causing a lessening of food and water intake, disturbing sleep, promoting nausea and vomiting, and by creating mental disturbance.[2]

## Tobacco Smoke Odors

Unlike body odor, the odor of tobacco smoke remains longer in the room and becomes peculiarly more offensive during the first three hours following the smoke period. Thus, the odor of stale tobacco smoke is more offensive than that of fresh smoke.[3] The immediate effects of exposure to high concentrations of tobacco smoke are the irritation of eyes and respiratory mucosa, and the constriction of small blood vessels, which decreases the blood supply to various parts of the body.

# STUDIES AND TESTS

The importance of keeping body and tobacco odors low in a shelter can be seen from the following study.[4] An experiment was conducted with five persons who smoked a total of six cigarettes during four hours of confinement in a sealed unpressurized room (185 cubic feet of air space per person). This produced in the occupants an oppressive feeling from the stuffy air and body odor. After these people left the room, breathed fresh air for a few minutes, and then returned, they found the air to be almost nauseating. This shows the significance of keeping the amount and intensity of objectionable odors low by adequate ventilation or other means. When a person enters an inadequately ventilated, occupied shelter, he will experience psychological and physiological stress from breathing the foul air.

## Tobacco Smoke Odor in Relation to Air Supply and Space

Yaglou[5] made an extensive study of ventilation requirements for cigarette smoke. In this study the strength of tobacco smoke was evaluated by sense of smell alone. Experiments were made in a test room containing 1,410 cubic feet of air space. The observers on the odor panel appraised the strength of odor and irritation, if any, by passing from the odor-free control room to the test room twice every hour. Nine subjects participated in each test, three non-smokers and six smokers, and they were stationed inside the test rooms. Only three of the latter smoked at any one time, taking turns with the three reserves. Each smoker was allowed to smoke four cigarettes per hour, and the toal number of cigarettes smoked per hour was approximately twenty-four.

In the winter, the control and test rooms were kept at 74 ± 2 F and around 27 percent relative humidity, and in the summer at 78 ± 3 F with 40 to 65 percent relative humidity. An outside air supply of 35 to 40 cfm per smoker was considered acceptable by the observers. In a room filled with tobacco smoke, body odor could seldom be detected.

Both smokers and non-smokers were exposed to various concentrations of tobacco smoke. The test subjects sat in armchairs, reading, writing, or conversing. An outdoor air supply of 25 cfm per smoker was considered acceptable by the non-smokers, but when the air supply was cut down to 14 cfm per smoker, the non-smokers experienced irritation of the eyes, nose and throat.

Yaglou states that the smokers were incapable of perceiving the smoke odor, as such, if they remained inside the smoking room, regardless of air flow. However, when ventilation became deficient, they were more susceptible to irritation of the eyes, nose, and throat than the non-smokers or the observers. Both smokers and non-smokers experienced a feeling of depression when the air supply was reduced to less than 15 cfm per smoker.

If cigarette smoking could be prohibited, shelter occupants would benefit greatly; however, veteran smokers would experience both psychological and physiological stress. Withdrawal symptoms, overt hostility, and increasing irritability were observed in heavy smokers during non-smoking tests aboard the nuclear submarine, USS TRITON, on her 84-day, submerged, world cruise.[6]

A small smoking room built inside large shelters with high ventilation rates would create better odor conditions in the main shelter area. Smoking room air could be supplied from the main shelter area, but to be effective, the exhaust air from the smoking room should bypass the main shelter.

Air Quality in Relation to Air Supply and Odor Intensity

Yaglou, Riley, and Coggins[1] studied the air quality in relation to outdoor air supply and body odor intensity in a 1,410-cubic-foot laboratory experimental room. The room was occupied by 3, 7, and 14 people to obtain three different air spaces of 100, 200, and 470 cubic feet per person. The air supply was varied from 0 to 30 cfm per person.

The impressions of air quality (good, fair, and poor) by the occupants, after exposure to the conditions of the room for 3.5 hours, were as follows:

<u>100 cubic feet of air space per person (14 people).</u> The air quality was fair to good when the air supply was above 13 cfm per person. Increase in ventilation rate above 25 cfm did not improve the quality of the air, as far as discrimination by the nose was concerned.

<u>200 cubic feet of air space per person (7 people).</u> The air quality was fair to good when the air supply was above 7 cfm per person. Increase in ventilation rate above 15 cfm per person had little or no effect on air quality, as far as discrimination by the nose was concerned.

470 cubic feet of air space per person (3 people). The air quality was good when the air supply was above 7 cfm per person, as far as discrimination by the nose was concerned.

The above study shows that the number of persons occupying a room and fresh outdoor air supply are important factors affecting the quality of air in an enclosed room. Air quality is also affected by (1) conditions which will tend to increase the production of perspiration, i.e., physical activity, anxiety, atmospheric conditions; (2) fungal infection of the skin; (3) inadequate personal hygiene facilities, e.g., bathing and washing; (4) bacterial decomposition of foodstuffs; and (5) noxious toilet odors.

No study including quantitative measurements or observations by a trained researcher has been made under conditions of stress. In general, physiologists are tempted to create traumatic situations which would provide for such observations in the laboratory but are restrained by ethics. The designer is faced with the undesirable alternative of introducing a margin of safety into a mechanical system to provide for such psychological stimulation of perspiration and body odor.

The Effect of Outdoor Air Temperature and Humidity on Air Quality

The outdoor temperature and humidity at the time of shelter occupancy will influence the amount of fresh air to be supplied for a shelter in order to maintain comfortable atmospheric conditions. The following shelter occupancy tests show the effect of outdoor air temperature and humidity on odor intensity and atmospheric conditions inside an enclosed structure:

1. A shelter-occupancy test with 45 participants was conducted in Waldrol, Germany during the winter of 1959. Each occupant was allotted approximately 6 cfm of outdoor air and approximately 40 cubic feet of air space during the 5-day test. An outside air temperature of 32 F and a relative humidity of 75 percent were recorded during the experiment; the inside temperature was 77 F with 72-percent relative humidity. Although the occupants lived in cramped quarters without the ordinary comforts of a home, they considered the 6 cfm of outdoor air supply per person adequate. The shelter air remained quite tolerable, with no unpleasant odors, even though the occupants were allowed to smoke as they wished.

2. In another underground shelter-occupancy test held at Yuma, Arizona, during the summer of 1958, the outdoor air temperatures ranged from 103-110 F. Forty military personnel occupied a corrugated-steel-arch underground structure for 24 hours with an allowance of approximately 90 cubic feet of air space per person and fresh outdoor air furnished by

a 200 cfm hand-operated blower (5 cfm of air per person). Toward the end of the 24-hour test, the occupants were very uncomfortable and complained of the high temperature (92 F) and humidity (high of 88 percent) inside the structure. The occupants were asked in a questionnaire if they were conscious of any non-human odors during confinement; 7.5 percent answered in the affirmative. They were not asked if they were conscious of any human odors. Ninety percent of the occupants stated that they were not bothered by cigarette smoking during confinement.[7]

The occupants probably were not aware of the objectionable body and tobacco odors because of fatigued sense of smell, and also because of the odor-suppressing effects of high temperature and humidity. The tests showed that a larger outdoor air supply and space are needed per person during hot weather than during cold weather.

At present, very little study has been done on ventilation requirements for shelters located in the tropic and desert areas; therefore, a field study is desirable to determine the optimum outdoor air supply or air space required per person to maintain comfortable atmospheric conditions.

### Effect of Temperature and Humidity on Odor Perception

Kerka and Humphreys[8] and Roberts[9] made a study of odor problems in air-conditioned spaces to determine the effects of temperature and humidity upon odor perception. When the relative humidity is increased, there is a general decrease in the odor-perception level. An increase in dry bulb temperature at constant specific humidity also causes a decrease in the odor-perception level. This is contrary to a general belief that high temperature and humidity accentuate odor in air.[2]

## CONTROL AND REMOVAL OF ODORS

### Odor Control by Increasing Temperature and Humidity

With certain odors, e.g., linoleum and upholstering, an increase in temperature and humidity will accelerate the volatilization of odors. Where the odor-generating source is independent of water vapor effects, viz., smoking and cooking, a high relative humidity and temperature is advantageous in depressing the sense of smell. However, occupants of a shelter would experience physical discomfort if humidity and temperature were increased to depress odor perception.

Odor-Removing Capacity of an Air Conditioning Process

Yaglou, Riley, and Coggins[1] indicated that "the usual processes of washing, humidifying, cooling, and dehumidifying recirculated air apparently removed a considerable amount of body odor, and under certain conditions practically the maximum amount possible by the use of known processes." The three different methods studies were:

1. Mixtures of outdoor and recirculated air passed through a conventional spray-type dehumidifier for cooling and dehumidifying the air of the experimental room during warm weather.

2. Mixtures passed through a centrifugal humidifier, for humidifying the air in cold weather.

3. Mixtures passed over a surface cooler through which cold water (between 35 and 50 F) was circulated.

The dehumidifier was the most efficient, and the surface cooler the least efficient. The absorption of odors by the centrifugal humidifier was only slightly greater than that of the surface cooler.

Three other processes[10] employed in air conditioning and air cleaning are refrigeration, electrostatic precipitation, and capillary-type action.

Refrigeration. It is used in conditioning air during periods of high ambient temperature.

Electrostatic Precipitation. This method is used primarily for removing foreign particles from the air. The particles of foreign matter are given a definite electrical charge when passing through an electrostatic field, and are then collected on metal plates of opposite polarity.

Capillary-type Air Conditioner. This type of apparatus employs multiple cells; each cell is filled with spun-glass filaments. It was developed for the purposes of air cleaning, humidification, cooling, or dehumidification.

An air-conditioning system which requires a large amount of water in its operation would be unsuitable for use in personnel shelters which have a limited water supply.

Suppression of Odors by Vapors

In addition to various ventilating systems to control odor in indoor air space, the use of deodorants to cover or eliminate objectionable odors in air is popular today.[11]

The deodorants function chiefly as masking agents; the principle of masking is to employ pleasant odor in sufficient concentration to cover the offending odor. Bath soap, incense, perfume, and aerosol spray are examples of masking agents, because they produce generally pleasant odors that will mask the odors of smoke, cooking, and the human body.

Paradichlorobenzene and formaldehyde, suitably perfumed, are among the vapors forming the basis of a type of evaporative equipment found in kitchens and bathrooms for deodorizing. The formaldehyde vapor tends to desensitize or deaden the olfactory sense temporarily, making it difficult or impossible to smell anything. It irritates the mucous membrane of the respiratory tract and produces harmful effects when used continuously in high concentrations.[12] Paradichlorobenzene vapor is also harmful in high concentration, but it is less harmful than formaldehyde vapor.

It is possible for two or more odorous substances to be present in the atmosphere at concentrations that would be perceptible if experienced alone, but when together they counteract one another to such an extent that neither is perceptible. This is referred to as odor cancellation or odor counteraction method.[9] In contrast with the strong odor level established by the masking technique, the odor counteraction method leaves no overriding odor, either pleasant or unpleasant, in the atmosphere.

A typical odor counteraction pair is formed by the vapor phases of ammonia and ionone. When the two vapors are combined in the atmosphere, the odor of neither the ammonia nor the ionone is evident to the observer. In another example, noxious calcium sulfide fumes which were escaping into the surrounding atmosphere from a large cement plant were successfully eliminated by counteraction sprays.[13]

None of the above references refer to a single counteracting agent for eliminating body odor and tobacco smoke from the air; therefore, literature, laboratory, and field studies are necessary to discover non-toxic, inexpensive, and effective counteracting agents for the removal of body odor and tobacco smoke from personnel shelters.

## Adsorption of Odors

Activated Charcoal. Activated coconut shell charcoal is employed for the control of odors and toxic vapors (war gases). It can be used in almost every situation where contaminants in vapor form should be removed from an enclosed space or prevented from entering an enclosed space from the outside. It is recommended because of its reliability, wide range of adsorbing characteristics, chemical stability, and availability.[14] It is available in cylindrical canisters, flat plates, accordion-pleated frames, and in bulk.

Activated charcoal literally traps odoriferous vapor or gas molecules on the surface of its millions of fine surface pockets. One pound of activated charcoal has over six million square feet of surface. Vaporous and gaseous molecules in the air are adsorbed in 1/3 second, and leave the air virtually odor-free.[15]

In order to keep odor intensity low in residences and offices, a non-smoker will require one pound, and a smoker two pounds, of activated charcoal per person per year. Where tobacco smoke odor is heavy, about five pounds of charcoal per person per year is required.[16]

For typical occupancies, one pound of activated coconut shell charcoal will purify for one year 2,000 cubic feet in residences and barracks buildings; 800 cubic feet in auditoriums, offices, or restaurants; 300 cubic feet in hospitals, conference rooms, or schools; and 100 cubic feet in air raid shelters or animal rooms.[17]

The air is generally odor-free after passing through a 1/2-inch-thick activated coconut shell charcoal filter. It has a pressure drop of 0.2 inches of water at an air flow of 40 fpm, and the efficiency of such an adsorber is approximately 95 percent. The pressure drop is about 0.1 inches of water with a partial-bypass-type of filter which has an efficiency of 30 percent. A 1-inch-thick filter has a pressure drop of 0.30 to 0.35 inches of water at an air flow of 40 fpm.[15]

Vapors highly adsorbed by activated charcoal (one pound adsorbs an average of 33.3 percent of its own weight) are odors from bodies, cooking, cigarette smoke, fish, perspiration, smog, and carbon tetrachloride. Examples of odorous vapors and particles adsorbed readily but not as highly as the above (one pound adsorbs an average of 16.7 percent of its own weight) are from animals, bacteria, automobile exhausts, chlorine, coal smoke, molds, pollens, viruses, poisonous gases and solvants. With the following vapors, activated charcoal is not satisfactory for use due to low-capacity adsorption: carbon dioxide, carbon monoxide, and hydrogen.[15]

<u>Impregnated Charcoal</u>. For most air conditioning applications, unimpregnated charcoals are adequate for atmospheric odor removal. Some toxic gases and vapors are not readily adsorbed by charcoal; however, it can be impregnated with silver, chromium, or copper to promote adsorption of a specific vapor or poisonous gas. The impregnants react either directly, with the gas being adsorbed, or they act as catalysts promoting physical adsorption, oxidation, decomposition, hydration, hydrolysis, and perhaps reduction.[18]

## CONCLUSIONS

1. The following methods are found to be effective in reducing body and tobacco odors in a shelter:

   a. To supply adequate fresh air through a simple ventilation system.

   b. To recirculate indoor air through an activated charcoal filter.

   c. To recirculate indoor air through a spray-type dehumidifier or a wet-coil air-conditioning exchanger.

   d. To use a capillary-type air conditioner.

   e. To employ deodorants and counteractants (in non-toxic concentrations).

   f. To increase temperature and relative humidity in a room (within limits of comfort).

The outdoor air temperature and humidity at the time of shelter occupancy will influence the amount of fresh air supply and space an individual needs to maintain comfortable atmospheric conditions inside a shelter.

2. Because a simple ventilation system is reliable and relatively inexpensive, its use to introduce fresh outdoor air is the preferred method for preventing the accumulation of odors inside a shelter.

3. A system designed to remove odorous vapors from the air stream by recirculating shelter air through efficient purification equipment may be necessary in planning for long periods of shelter occupancy.

4. Olfactory fatigue may cause a person inside a shelter to be unaware of foul body and tobacco odors. However, when entering an inadequately ventilated shelter from the outside, he experiences psychological and physiological stress from smelling the foul odors.

5. The important factors which affect the quality of air in an enclosed room are: the number of occupants, fresh air supply, toilet odors, skin infection, heat, humidity, anxiety, perspirations, and decomposition of foodstuffs.

6. For a simple ventilation system, the minimum air space and outdoor air supply required per person were obtained by extrapolating the results of laboratory experiments and shelter occupancy tests; they are as follows:

a. <u>In hot weather</u>. 20 cfm of fresh air (refrigeration may be required) and 100 cubic feet of space per person.

b. <u>In temperate weather</u>. 10 cfm of fresh air and 70 cubic feet of space per person.

c. <u>In cold weather</u>. 7 cfm of fresh air and 50 cubic feet of space per person.

The above values should not be taken as final answers to the shelter air supply problem; further work is needed, especially for shelters in tropical and desert areas. The atmospheric conditions inside a shelter become critical when the outdoor air temperature is well in excess of body temperatures, and when the relative humidity is so high as to interfere with the body cooling system. The 20 cfm of outdoor air during hot weather may be totally inadequate under these conditions, and a refrigeration unit may be required in the shelter.

## RECOMMENDATIONS

1. That a system for recirculating indoor air through an activated charcoal filter to remove odorous vapors be installed inside all closed shelters.

2. That a small smoking room for a limited number of occupants be installed inside large shelters.

3. That a field study be initiated to determine ventilation requirements for shelters located in tropic and desert areas. (Methods of cooling air inside these shelters should be considered.)

4. That a feasibility and availability study be initiated to discover agents for counteracting noxious odors in enclosed spaces.

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